DTU Library

Achieving health benefits from carbon reductions: Manual for CaRBonH calculation tool

Spadaro, Joseph V. ; Kendrovski, Vladimir; Sanchez Martinez, Gerardo

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

World Health Organization

REGIONAL OFFICE FOR Europe

ACHIEVING HEALTH BENEFITS FROM CARBON REDUCTIONS

Manual for CaRBonH calculation tool

World Health Organization

REGIONAL OFFICE FOR Europe

ACHIEVING HEALTH BENEFITS FROM CARBON REDUCTIONS

Manual for CaRBonH calculation tool

ABSTRACT

The Carbon Reduction Benefits on Health (CaRBonH) calculation tool allows quantification of the physical and economic consequences for human health achieved through improvements in country-level air quality from domestic carbon reductions, specifically policy mitigation actions and measures as reported in the NDCs submitted by the Conference of the Parties to the UNFCCC in support of the objectives as set out in Article 2 of the Convention.

Keywords

CARBON - ANALYSIS
AIR POLLUTANTS - ANALYSIS
DATA COLLECTION – METHODS
ENVIRONMENTAL MONITORING - METHODS
CLIMATE CHANGE
GREENHOUSE EFFECT
RISK ASSESSMENT
POLICY MAKING

Address requests about publications of the WHO Regional Office for Europe to:
Publications
WHO Regional Office for Europe
UN City, Marmorvej 51
DK-2100 Copenhagen Ø, Denmark
Alternatively, complete an online request form for documentation, health information, or for permission to quote or translate, on the Regional Office website (http://www.euro.who.int/pubrequest).

Contents

List of tables

List of figures

Acknowledgments

This calculation tool and manual has been developed by Joseph V. Spadaro, in collaboration with Vladimir Kendrovski and Gerardo Martinez Sanchez of the WHO European Centre for Environment and Health. Valuable comments were provided by the following participants in a Meeting on the Health Co-Benefits of Mitigation from Intended Nationally Determined Contributions, held in Bonn on 23 February 2017:

Emmanuel Ackom, Partnership between the United Nations Environment Programme and the Technical University of Denmark, Copenhagen, Denmark
Diarmid Campbell-Lendrum, Scientist, WHO headquarters, Geneva, Switzerland
Frank George, Technical Officer, WHO Regional Office for Europe, Copenhagen, Denmark
Marisol Yglesias Gonzalez, Intern, WHO Regional Office for Europe, Copenhagen, Denmark
Sophie Gumy, Technical Officer, WHO headquarters, Geneva, Switzerland
Bernd Hackmann, Programme Officer, United Nations Framework Convention on Climate Change, Bonn, Germany
Andrew Haines, London School of Hygiene and Tropical Medicine, London, United Kingdom of Great Britain and Northern Ireland
Dorota Jarosinska, Programme Manager, WHO Regional Office for Europe, Copenhagen, Denmark
Melissa Lott, University College London, United Kingdom
Vojtech Maca, Charles University, Prague, Czech Republic
Barbara Muik, Programme Officer, United Nations Framework Convention on Climate Change, Bonn, Germany
Srdan Matic, Environment and Health Coordinator, WHO Regional Office for Europe, Copenhagen, Denmark
Pierpaolo Mudu, Technical Officer, WHO Regional Office for Europe, Copenhagen, Denmark
Niranjan Mukherjee, Intern, WHO Regional Office for Europe, Copenhagen, Denmark
Elizabet Paunovic, Head, European Centre for Environment and Health, WHO Regional Office for Europe, Copenhagen, Denmark
Oliver Schmoll, Programme Manager, WHO Regional Office for Europe, Copenhagen, Denmark
Hanna Yang, Consultant, WHO Regional Office for Europe, Copenhagen, Denmark.

List of abbreviations

CO_2	carbon dioxide
COP	Conference of Parties
CRF	concentration–response function
EMEP	European Monitoring and Evaluation Programme
GDP	gross domestic product
ISO	International Organization for Standardization
NDC	nationally determined contribution
NH_3	ammonia
NOx	unspecified mixture of nitrogen oxides
PM	particulate matter
PPM	primary particulate matter
SO_2	sulfur dioxide
UNFCCC	United Nations Framework Convention on Climate Change
ΔC	Change in $PM_{2.5}$ ambient concentration

(Intended) nationally determined contributions and the Paris Agreement

The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC), which was adopted at the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992, entered into force on 21 March 1994 *(1)*. At the Conference, the world community came together and acknowledged the long-term negative environmental consequences associated with rapidly increasing anthropogenic emissions of climate-altering pollutants. Country delegates reached a consensus on the urgency for coordinated, comprehensive actions at all levels of society – local, national, regional and global – to meaningfully mitigate future emissions as well as adapt to climate variability and long-term change. Contingency and adaptation interventions are meant to curb the most adverse effects of climate change on the natural and built environments, ecosystems and health systems, and act to limit community exposure and related climate risks, including health burdens, and the potential for population displacement and increased social conflicts.

Among the specific goals set by the UNFCCC, Article 2 reads as follows *(1)*.

> The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

In addition, industrialized nations:

- committed themselves to lead efforts to limit climate-altering pollutants emissions (Annex I);
- agreed to provide technical assistance, share technology with poorer countries and establish financial mechanisms in support of actions against climate change; and
- established a routine accounting and reporting framework for the implementation of national climate change mitigation policies and measures, tracking of emissions inventory and consideration of arrangements for adaption (manage the unavoidable).

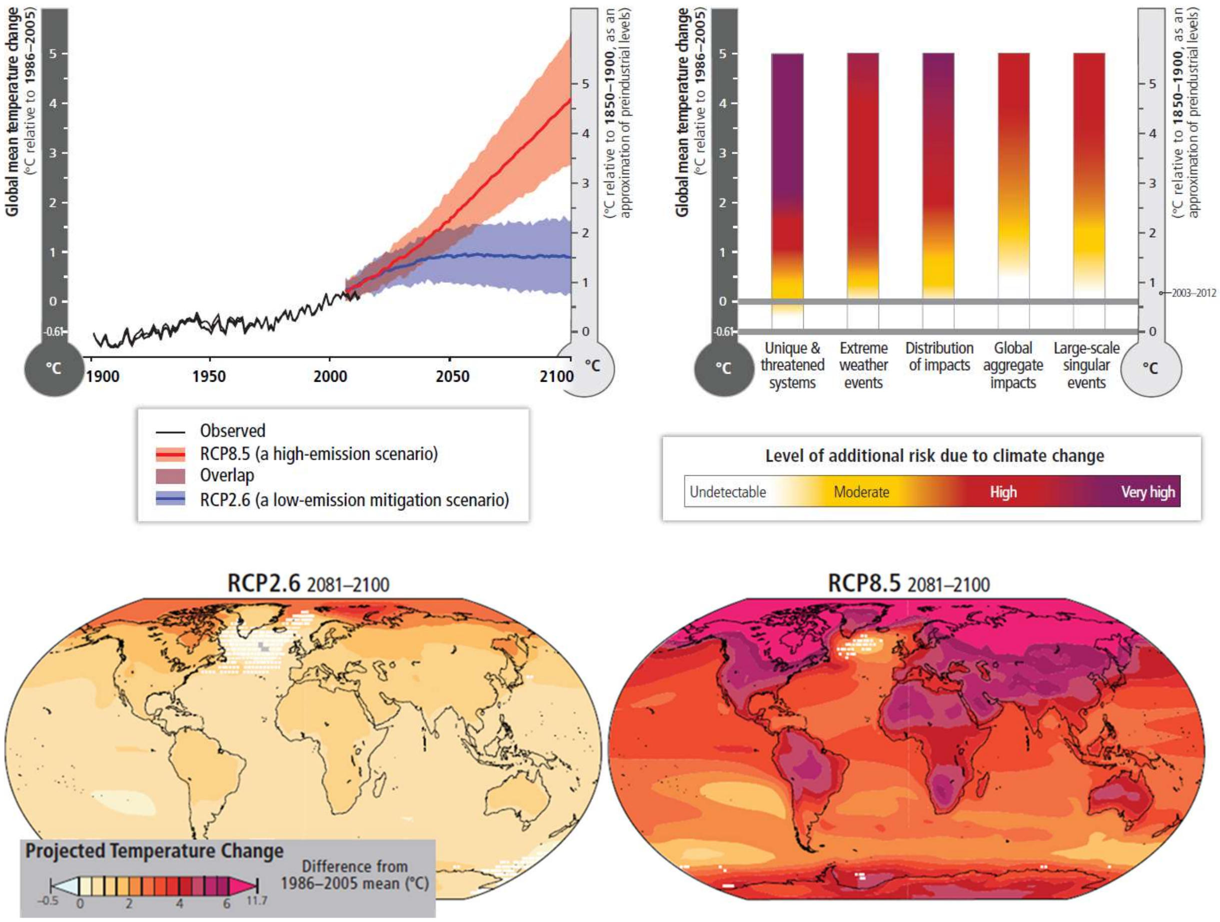
Sustainable human development may be defined as living in a world where consumption demands less of the ecosystem services that the earth can deliver without compromising the needs of future generations. Economic and social development requires a holistic approach underpinned by sound economic analysis that also promotes environmental protection while enabling all peoples to share equally in the opportunities and benefits of social development regardless of social or economic status and gender. The risks of different economic development strategies therefore need to be assessed and the results communicated to decision-makers and the general public in a transparent and concise way that takes account of socioeconomic trade-offs and uncertainties on present and future generations.

The Paris Agreement on Climate Change

In 2011, the United Nations Climate Change Conference of Parties (COP17) established the Durban Platform with the goal of adopting a legally binding instrument by 2015 in which all Parties would commit themselves to domestic action to mitigate greenhouse gas emissions beyond 2020 in an effort to stabilize ambient concentrations and prevent global mean surface temperature change from exceeding a threshold of 2 °C by the end of the 21st century. Furthermore, countries would attempt to make additional efforts to limit ambient temperatures to below 1.5 °C (Fig. 1). The IPCC SR1.5 report[1] forms an official collection of all known scientific, peer-reviewed, research on the impacts of 1.5°C of global warming on natural and human systems around the world.

[1] www.ipcc.ch/report/sr15/

Fig. 1. Global temperature changes and issues for concern due to increasing levels of climate change



Source: Intergovernmental Panel on Climate Change *(2).*

The Paris Agreement, which was adopted by delegates to the Conference of Parties of the UNFCCC in Paris in 2015 (COP21) *(3)*, reflects a changing landscape in international climate policy with renewed emphasis on mitigating greenhouse gas emissions and preparing for and managing the current and projected consequences of a changing climate (adaptation). The Agreement formalized countries' commitments to achieve climate-related policy goals/targets through their nationally determined contributions (NDCs). The Agreement went into effect on 4 November 2016; by November 2017 it had been signed by 195 parties and ratified by 170 countries, collectively representing 87.9% of global industrialized emissions.

Linking carbon reductions to health benefits

The Paris Agreement represents an opportunity and a challenge for nations to promote policy-making and social awareness of the co-benefits on health from reducing emissions of health-damaging pollutants through implementation of climate-friendly policies and adaptation action, as outlined in the communications relating to their pledged NDCs *(4)*.

Thus, it is worth examining which consequential environmental and health benefits have been achieved through reductions in domestic carbon emissions for the proposed climate policies under the NDCs submitted by Member States of the WHO European Region to the UNFCCC.

To answer this question, an Excel-based tool has been developed for the 53 Member States in the Region that quantifies the health and related economic gains from implementation of the NDCs. Such a tool can be used as a mechanism to assess the outcome of climate-driven policies and to promote decision-making in settings where there is limited data availability.

Overview of the Carbon Reduction Benefits on Health (CaRBonH) calculation tool

Scope of the tool

The aim of the Carbon Reduction Benefits on Health (CaRBonH) calculation tool is to quantify the physical and economic consequences for human health achieved through improvements in country-level air quality from domestic carbon reductions, specifically policy mitigation actions and measures as reported in the NDCs submitted by the Conference of the Parties to the UNFCCC in support of the objectives as set out in Article 2 of the Convention.

Description of the tool

A flowchart of the tool is presented in Fig. 2. The Excel workbook consists of nine worksheets, covering:

(i) user input on pollutant emission reductions from carbon mitigation interventions by country (worksheet *Emission reductions*);

(ii) endogenous calculations of changes in population exposure from saved emissions;

(iii) calculation of health benefits in the susceptible population in terms of reduced incidences of annual morbidity, postponed mortality (deaths) and gains in years of life expectancy, together with an economic valuation of health benefits achieved from carbon reductions (worksheet *Summary of results*); and

(iv) two worksheets with preloaded default statistics on demographic and epidemiological data by country for 2010, 2020 and 2030.

Health hazards are calculated using an impact pathway analysis, which explicitly traces the fate of pollutants from the moment they are released into the environment, followed by atmospheric dispersion and eventual removal by deposition and chemical transformation (Fig. 3). Health outcomes are calculated using epidemiological associations (risk functions that link population response to changes in ambient exposure level). The health benefits of reduced air pollution are transformed into economic costs using *unit health costs*, that is, cost per case of disease or death. Unit costs combine both market and non-market elements in determining an equivalent monetary value that accounts for direct impacts on the gross domestic product (GDP) of a nation, and indirect impacts on social welfare due to pain and suffering while someone is ill.

User input

Reductions in emissions of greenhouse gases and other pollutants, including primary particulate matter (PPM) of aerodynamic diameter less than 2.5 µm,[2] sulfur dioxide (SO_2), nitrogen oxides (NOx), and ammonia (NH_3) are entered in the worksheet *Emission reductions* (Fig. 4, 5). Input is differentiated by emitter country for 2020 and 2030 (users may enter information for either or both years). GHG reductions are specified with respect to a particular base year, while reductions of other pollutants are compared against a business as usual emissions scenario. The Region is divided into 22 subdivisions, including countries belonging to the European Union (EU) after July 2013 (EU28),[3] Belarus, Israel, the Republic of Moldova, the Russian Federation, Turkey, Ukraine and eastern European and central Asian countries. Data may be entered for a single country/region or for a group of countries (for example, Annex I countries only). Emission reductions by pollutant type for Andorra, Monaco and San Marino are added to EU28 values. For this block of countries, the tool calculates a single estimate of $PM_{2.5}$ exposure change, health gains and economic benefits. When only PM_{10} emissions data are available, $PM_{2.5}$ to PM_{10} mass conversion factors may be applied to estimate changes in $PM_{2.5}$ emissions. These conversion factors vary by country; default values have been summarized in the worksheet *Effect PPM reduction on PM2.5*. Other than emission reductions, the tool requires no additional input from the user.

[2] 1 µm = one-millionth (10^{-6}) of a metre, or micron.

[3] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland.

Fig. 2. Carbon Reduction Benefits on Health (CaRBonH) software tool at a glance

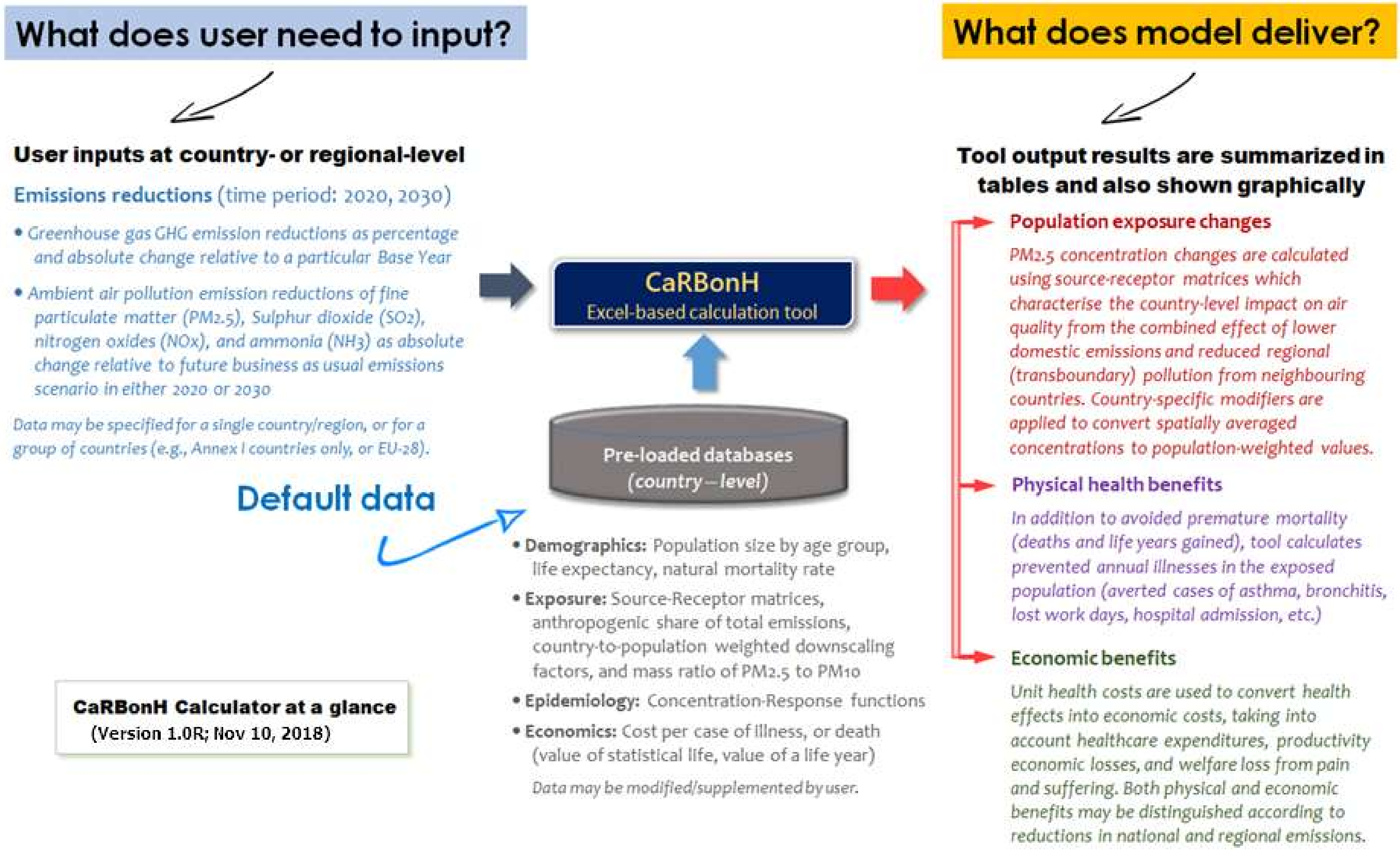
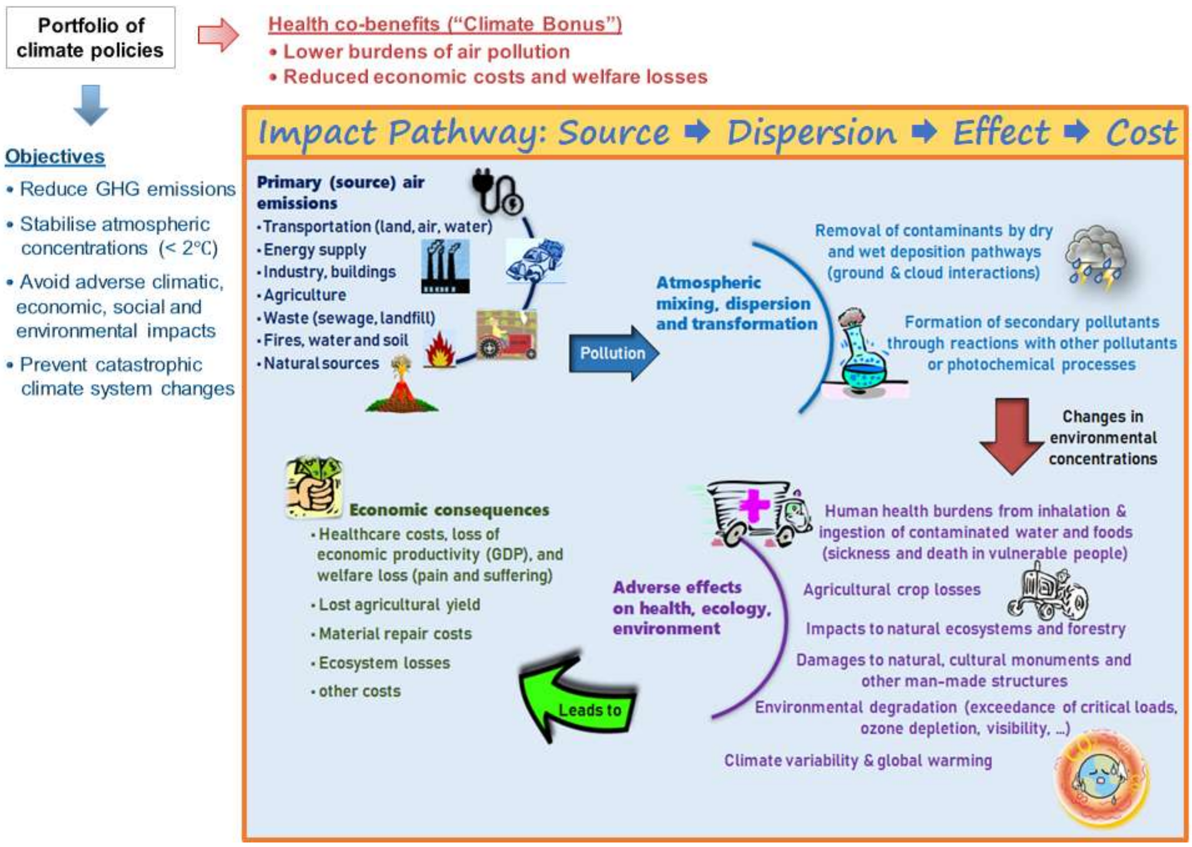


Fig. 3. Methodological framework implemented in the CaRBonH calculation tool



Tool output – exposure calculations

Changes in $PM_{2.5}$ concentrations due to reductions in domestic and regional $PM_{2.5}$, SO_2, NOx and NH_3 emissions are provided in the four worksheets *Effect xxx reduction on PM2.5*, where xxx stands for PPM, SO_2, NOx and NH_3. Country-to-country blame matrices, also known as source-receptor tables, are used to calculate population exposure changes. These matrices are look-up tables used to calculate concentration changes in a receptor (receiving) country due to domestic emission reductions as well as attributions from emissions changes in neighbouring emitter (polluter) countries that feed into transboundary pollution at the regional level (Table 1). These data have been calculated by the European Monitoring and Evaluation Programme of the European Commission *(5)*, and have been supplemented with further calculations carried out with the uniform world model developed by Spadaro *(6)*. The contribution to the total change in ambient $PM_{2.5}$ concentrations from decreases in national and regional emissions is shown in Fig. 6 Country-specific modifier factors (Table 2) are used to compute changes in population-weighted exposures, starting with geographically averaged concentrations (Table 3, 4). The modifier factors are summarized by country in the worksheet *Effect PPM reduction on PM2.5*.

Tool output – health gains and economic benefit calculations

Output results are summarized in tables and shown graphically in the worksheet *Summary of results*. In addition to summarizing user input information and other country statistics, this worksheet shows the health and economic co-benefits of carbon mitigation interventions that may be achieved through improvements in air quality as a result of reductions in air pollutant emissions. CaRBonH apportions the results according to reductions in national emissions plus additional health benefits achieved from emission reductions that occur in other countries – the transboundary pollution effect (Fig. 7). Susceptible population subgroups, such as children and sick and elderly people, who are exposed to atmospheric contaminants are at a higher risk of suffering from adverse health symptoms ranging from mild discomfort to more serious life-threatening conditions. The quantified health benefits of reduced emissions include prevented cases of illness (morbidity), fewer premature deaths and life years gained from an extension in life expectancy among the exposed population (Table 5, Fig. 8).

Fig. 4. Air emissions avoided from implementation of NDC carbon reductions in 2030

USER INPUT

Ambient emission reductions for 2020 and 2030

Comments

- *Annual data are specific to future reductions in emissions for a single country or a group of countries. The EU-28 is treated as one single region in the modeling of health impacts and costs. The cumulative emissions include the traditional 28 Member States of the European Union plus Andorra, Monaco, and San Marino.*
- *Definitions: PM2.5 = particulate matter of less than 2.5 µm aerodynamic diameter; SO2 = sulfur dioxide; NOx = mixture of nitrogen oxides; NH3 = ammonia; GHG = greenhouse gas emissions (in CO2 equivalent)*

Base year for GHG reductions: 1990

Select base year

This worksheet shows pollutant emission reductions used as inputs in the WHO Policy Brief (June 2017).

For the following four countries, GHG emissions increase in 2030 compared to base year 1990, but emissions grow slower by 2030 relative to the business as usual scenario for that year (baseline reduction target). Averted GHG emissions lead to reductions in emissions of other pollutants.

** Bosnia & Herzegovina: 0.8 MtCO2 averted in 2030, or 2% reduction (18% higher than 1990),
** Israel: 23.9 MtCO2 averted in 2030, or 23% reduction (11% higher than 1990),
** Macedonia, FYR: 5.2 MtCO2 averted in 2030, or 30% reduction (29% higher than 1990),
** Turkey: 246 MtCO2 averted in 2030, or 21% reduction (392% higher than 1990).

1 Mt (mega-tonne) = 1 Tera-grams (10^12 grams)

Enter comments

	Emission reductions in kilo-tonnes per year in 2030					
Country/Region	**GHG % base year**	**GHG Reduction**	**$PM_{2.5}$**	**SO_2**	**NOx**	**NH_3**
Albania	23.6%	1,700	0.10	0.45	0.29	
Armenia	27.7%	6,900	0.43	0.73	4.70	
Azerbaijan	35.0%	25,700	6.20	20.60	28.80	
Belarus	28.0%	38,900	3.40	11.20	10.80	
Bosnia and Herzegovina	-18.0%	-6,100	0.06	1.40	0.18	
Georgia	32.0%	15,400	3.50	4.10	9.20	
Iceland	40.0%	1,900	0.02	0.24	0.80	
Israel	-11.1%	-8,200	0.29	9.90	7.00	
Kazakhstan	15.0%	53,700	4.20	133.00	24.00	
Kyrgyzstan	59.1%	17,900	0.17	1.30	1.30	
Montenegro	30.0%	1,600	0.07	0.20	0.11	
Norway	40.0%	20,800	0.58	8.30	11.40	
Republic of Moldova	65.5%	28,400	0.14	0.23	0.23	
Russian Federation	27.5%	926,000	126.00	518.00	130.00	
Serbia	9.8%	7,900	0.30	3.60	0.95	
Switzerland	50.0%	26,700	0.25	3.50	5.20	
Tajikistan	15.0%	3,800	1.50	5.30	4.00	
The FYR of Macedonia	-29.1%	-2,800	1.10	19.00	3.30	
Turkey	-392.2%	-737,000	24.00	243.00	64.00	
Turkmenistan	-167.7%	-85,200				
Ukraine	40.0%	378,000	4.10	22.00	8.80	
EU-28	40.0%	2,250,000	287.00	914.00	951.00	

Enter emission reductions for year 2030

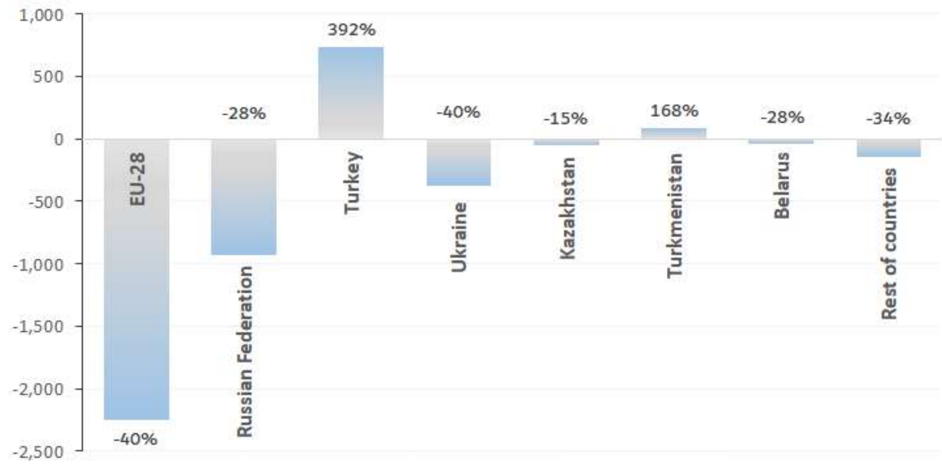
The FYR of Macedonia = The former Yugoslav Republic of Macedonia.

Notes.

- Reductions in greenhouse gas emissions are based on NDC pledges and historical data from the UNFCCC (Table 13). Negative values indicate an increase in emissions over the base year. NDC targets are typically specified relative to a base year (1990 in this example) compared to a future baseline (in this example, 2030 for Israel) or in terms of reduced carbon intensity (greenhouse gas emissions per unit of GDP, for example, in the case of Uzbekistan).
- For the other pollutants, emissions avoided in 2030 are estimated using published results by the Greenhouse gas – air pollution interactions and synergies Europe model *(15)*. The model identifies synergies and trade-offs from limiting local and regional air pollution and mitigation of greenhouse gas emissions.
- By 2030, the proposed policies would reduce emissions of $PM_{2.5}$ by 17%, SO_2 by 25%, and NOx by 13% from 1990 levels.

A copy of the WHO policy brief is available *(11)*.

Fig. 5. Reduced emissions (mega-tonnes of carbon dioxide (CO_2) equivalent) of the greenhouse gases shown in Fig. 4, and relative changes in 2030 compared to 1990 levels (net emission reduction 2966 metric tons CO_2 equivalent)



Rest of countries = remaining countries shown in Fig. 4

Note. The chart shows the absolute and relative changes from implementation of proposed NDC pledges. Most countries have set targets to reduce carbon emissions below 1990 levels, while others (such as Turkey) have set emission caps or intend to reduce future emission growth rates relative to a business as usual scenario. Further reductions could be achieved through international cooperation, knowledge sharing and financial support.

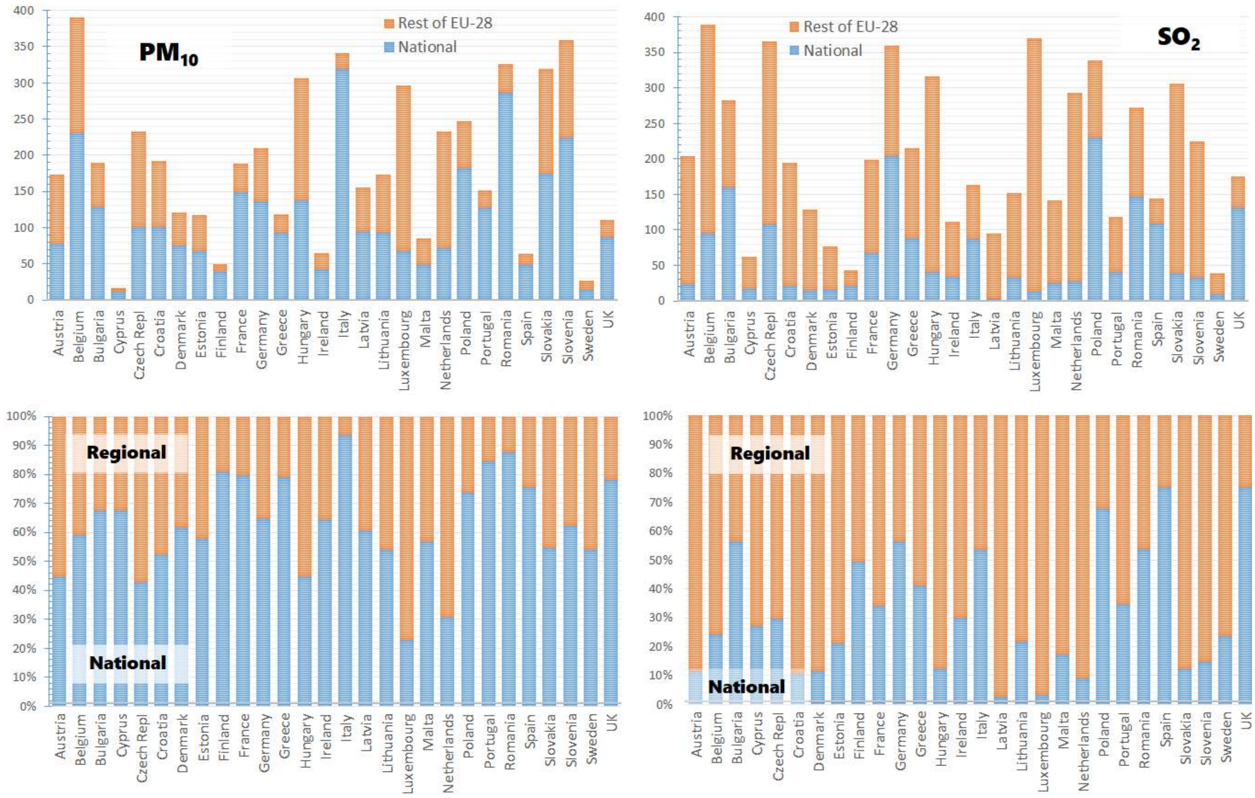
Table 1. Example of a source-receptor table for changes in PPM (PM_{10}) emissions

Receptor country ↓		Emitter country → AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK
Emissions reduction (kt) →		1.65	0.90	4.95	3.60	3.90	6.45	6.30	10.50	2.70	0.30	5.85	34.20	4.80
		AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK
Albania	AL	103.1	0.0	0.4	0.0	1.8	0.1	1.6	0.1	0.0	0.0	0.5	0.6	0.0
Armenia	AM	0.0	44.8	0.0	21.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Austria	AT	0.0	0.0	77.3	0.0	0.6	0.4	0.2	0.3	1.9	0.0	9.2	18.3	0.3
Azerbaijan	AZ	0.0	3.9	0.0	99.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bosnia and Herzegovina	BA	1.4	0.0	2.1	0.0	79.0	0.2	0.7	0.3	0.1	0.0	2.3	2.2	0.1
Belgium	BE	0.0	0.0	0.4	0.0	0.0	230.2	0.0	0.3	0.5	0.0	1.5	43.2	1.2
Bulgaria	BG	0.6	0.0	0.6	0.0	0.9	0.1	128.2	0.8	0.1	0.0	0.8	1.1	0.1
Belarus	BY	0.0	0.0	0.4	0.0	0.2	0.3	0.5	94.9	0.1	0.0	1.2	2.2	0.5
Switzerland	CH	0.0	0.0	4.0	0.0	0.0	0.7	0.0	0.0	75.8	0.0	0.7	18.6	0.1
Cyprus	CY	0.1	0.0	0.0	0.0	0.1	0.0	0.4	0.1	0.0	11.0	0.0	0.1	0.0
Czech Republic	CZ	0.1	0.0	11.6	0.0	0.7	1.0	0.3	0.8	0.9	0.0	100.0	28.0	0.7
Germany	DE	0.0	0.0	6.5	0.0	0.1	8.8	0.0	0.5	3.9	0.0	6.9	135.9	3.3
Denmark	DK	0.0	0.0	0.2	0.0	0.0	3.1	0.0	0.6	0.1	0.0	0.7	13.6	75.0
Estonia	EE	0.0	0.0	0.1	0.0	0.1	0.4	0.2	3.3	0.0	0.0	0.3	1.7	1.3
Spain	ES	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.5	0.0
Finland	FI	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.1	0.3	0.4
France	FR	0.0	0.0	0.4	0.0	0.0	8.6	0.0	0.1	2.4	0.0	0.7	12.4	0.3
Tajikistan	TJ	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turkmenistan	TM	0.0	0.1	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turkey	TR	0.0	0.6	0.0	0.3	0.1	0.0	1.2	0.2	0.0	0.1	0.1	0.1	0.0
Ukraine	UA	0.1	0.0	0.3	0.2	0.3	0.2	1.7	7.2	0.0	0.0	0.8	1.2	0.2
Uzbekistan	UZ	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
EU-28	EU-28	0.2	0.0	3.2	0.0	0.6	4.4	4.4	1.1	0.8	0.0	4.0	16.5	1.8
		AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK

Source: European Modelling and Evaluation Programme (EMEP) *(5)*.

Note. Interpretation of table entries: change in background concentrations of $PM_{2.5}$ (ng/m^3) in receiver country (row) due to a specified reduction in emissions of PPM (PM_{10}) in emitter country (column).

Fig. 6. $PM_{2.5}$ change (ng/m^3) for a uniform 15% reduction of PM_{10} and SO_2 emissions in EU28 countries



Source: EMEP *(5).*

Note. Cuts in SO_2 emissions contribute to lower concentrations of sulfates, a secondary chemically derived component of $PM_{2.5}$, which have a stronger regional impact than reductions in emissions of primary PM.

Health effects are calculated using the WHO Health risks of air pollution in Europe – HRAPIE project set of recommended relative risks for Europe *(7)*, which cover bronchitis and asthma attacks in children, chronic bronchitis and work lost days (WLD) in adults, and other illnesses that affect a person's normal daily routine (in other words, restricted activity days), or worse yet may require hospital admission because of cardiopulmonary system complications. The relative risk is defined as the ratio of health hazards for two populations exposed to different levels of pollution. These coefficients are determined through epidemiological studies, and relate an exposure increment to an increase in the prevalence of illness or baseline mortality in the population of concern. Relative risks are transformed into concentration–response functions (CRF) – the annual burden per person and per unit concentration – using country-specific data such as illness or mortality baseline rate and share of the population affected by the health outcome of concern (Fig. 9). Since demographic data vary by year, so do the CRFs.

Finally, an economic value is put on health benefits (Table 6, Fig. 10), taking into consideration the health care expenditure and productivity losses (market costs) prevented plus the social costs (welfare benefit) attributed to premature deaths averted or life-years gained *(8)*. Postponed mortality is valued using the value of statistical life, the price that society is willing to pay to prevent an anonymous (statistical) death, while life extension is valued using the value of a life-year. Mortality benefits are not market costs; instead the economic benefits represent a gain in social well-being from reduced pain and suffering caused by environmental stressors such as air pollution. Morbidity costs are market expenditures (included in the transaction costs of doing business), and have a direct consequence on the country's GDP. At the level of the citizen, illness has direct consequences on the quality of life and indirect consequences on personal income and savings.

Table 2. Parameters used in CaRBonH for calculations of changes in population exposure in Table 3

Country/Region	Modifier factors	Anthropogenic share of PM2.5 concentration	Ratio PM2.5 to PM10
Albania	2.1	82%	0.51
Armenia	6.8	66%	0.61
Austria	2.5	93%	0.73
Azerbaijan	3.6	49%	0.61
Belarus	2.9	88%	0.61
Belgium	1.4	95%	0.68
Bosnia and Herzegovina	4.8	85%	0.61
Bulgaria	3.4	83%	0.68
Croatia	2.4	87%	0.61
Cyprus	1.6	73%	0.44
Czech Republic	2.1	94%	0.75
Denmark	2.0	83%	0.46
Estonia	1.9	72%	0.49
Finland	4.3	75%	0.51
France	1.8	87%	0.63
Georgia	4.4	61%	0.61
Germany	1.4	90%	0.70
Greece	1.7	73%	0.38
Hungary	2.2	94%	0.80
Iceland	0.7	8%	0.62
Ireland	1.1	32%	0.63
Italy	2.0	87%	0.67
Kazakhstan	2.5	38%	0.40
Kyrgyzstan	1.5	49%	0.40
Latvia	3.7	82%	0.68
Lithuania	2.9	87%	0.68
Luxembourg	1.5	90%	0.72
Malta	2.2	53%	0.46
Montenegro	3.9	88%	0.65
Netherlands	1.6	96%	0.64
Norway	10.5	66%	0.47
Poland	2.6	90%	0.75
Portugal	2.6	67%	0.71
Republic of Moldova	2.4	88%	0.61
Romania	1.9	84%	0.72
Russian Federation	6.1	72%	0.61
Serbia	1.9	88%	0.61
Slovakia	2.2	95%	0.67
Slovenia	2.0	89%	0.76
Spain	2.6	66%	0.55
Sweden	3.6	68%	0.31
Switzerland	1.9	89%	0.70
Tajikistan	6.2	70%	0.40
The FYR of Macedonia	3.9	83%	0.59
Turkey	2.6	79%	0.61
Turkmenistan	0.8	10%	0.40
Ukraine	2.1	87%	0.61
United Kingdom	2.3	84%	0.69
Uzbekistan	3.5	54%	0.40
EU-28	2.3	84%	0.65

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software (worksheet *Effect PPM reduction on PM2.5*).

Table 3. $PM_{2.5}$ exposure change (ng/m^3) from reduced $PM_{2.5}$ emissions shown in Fig. 4

Receptor country →; Emitter country ↓

Country/Region	ISO Country code	$PM_{2.5}$ reduced	Population-weighted PM2.5 concentration change (ng/m3) in "Emitter" and "Receptor" countries																						
			AL	AM	AZ	BY	BA	GE	IS	IL	KZT	KG	ME	NO	MD	RUE	RS	CH	TJ	MK	TR	TM	UA	UZ	EU-28
Albania	AL	0.1	25.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.9	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.1
Armenia	AM	0.4	0.0	239.4	11.1	0.0	0.0	9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.2	0.1	0.0	0.2	0.0
Azerbaijan	AZ	6.2	0.0	411.1	1004.7	0.1	0.0	138.6	0.0	0.0	1.3	0.3	0.0	0.0	0.3	2.5	0.0	0.0	1.7	0.0	2.3	2.7	1.0	4.0	0.0
Belarus	BY	3.4	0.1	0.0	0.0	147.3	0.7	0.1	0.0	0.1	0.2	0.0	0.3	0.2	4.5	2.3	0.5	0.0	0.0	0.5	0.3	0.0	8.2	0.1	1.4
Bosnia and Herzegovina	BA	0.1	0.1	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Georgia	GE	3.5	0.0	190.1	142.0	0.5	0.0	1064.4	0.0	0.0	0.4	0.1	0.0	0.0	1.5	1.9	0.1	0.0	0.4	0.1	3.8	0.6	1.8	1.1	0.0
Iceland	IS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Israel	IL	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.0	16.6	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.1
Kazakhstan	KZT	4.2	0.0	0.4	0.8	0.1	0.0	0.2	0.0	0.1	30.9	5.5	0.0	0.0	0.1	4.0	0.0	0.0	4.1	0.0	0.0	1.0	0.2	13.6	0.0
Kyrgyzstan	KG	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	7.7	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	1.8	0.0
Montenegro	ME	0.1	0.7	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	15.8	0.0	0.0	0.0	0.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Norway	NO	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Republic of Moldova	MD	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	1.1	0.0	0.1
Russian Federation	RUE	126.0	0.9	10.7	40.5	49.8	1.5	37.7	0.0	0.2	38.1	0.4	1.2	4.9	17.4	245.4	1.5	0.0	2.3	2.8	5.7	3.7	52.6	18.4	3.4
Serbia	RS	0.3	4.2	0.0	0.0	0.1	4.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.2	0.0	21.2	0.0	0.0	9.8	0.1	0.0	0.1	0.0	0.3
Switzerland	CH	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Tajikistan	TJ	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.8	0.0	0.0	0.0	0.0	0.0	0.0	260.3	0.0	0.0	0.7	0.0	18.2	0.0
The FYR of Macedonia	MK	1.1	18.0	0.0	0.0	0.1	1.4	0.0	0.0	0.2	0.0	0.0	3.4	0.0	0.4	0.0	11.2	0.0	0.0	264.9	0.2	0.0	0.2	0.0	0.6
Turkey	TR	24.0	1.1	56.0	6.6	3.6	0.8	19.1	0.0	24.2	0.2	0.2	1.2	0.0	13.0	0.9	2.5	0.0	0.9	4.9	247.6	0.3	5.7	0.9	1.7
Turkmenistan	TM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ukraine	UA	4.1	0.3	0.3	0.7	6.1	0.5	0.6	0.0	0.0	0.6	0.0	0.4	0.0	16.1	2.6	0.6	0.0	0.0	1.0	1.1	0.1	44.6	0.5	0.5
Uzbekistan	UZ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU-28	EU-28	287.0	140.2	3.7	2.2	247.7	397.7	4.0	1.6	49.0	2.2	0.0	120.9	60.4	522.8	25.0	247.4	210.7	-0.1	472.6	19.9	0.4	162.0	1.7	590.6
Total concentration change in Receptor country (ng/m3)			192	912	1,209	456	419	1,274	2	90	75	19	156	128	593	285	287	230	271	763	283	10	278	60	600
Share of total concentration change due to national emission reductions			13%	26%	83%	32%	2%	84%	9%	18%	41%	41%	10%	49%	3%	86%	7%	8%	96%	35%	88%	0%	16%	0%	98%

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

$$\begin{matrix}\mathit{Population\ weighted}\\ \mathit{concentration\ change}\ \Delta C\\ \mathit{in\ receptor\ country}\end{matrix} = \begin{matrix}\Delta C\ (\mathit{receptor})\ \mathit{per}\\ \mathit{kt\ emission}\ (\mathit{emitter})\end{matrix} \times \begin{matrix}\mathit{Emissions}\\ \mathit{reduction}\ (\mathit{emitter})\end{matrix} \times \begin{matrix}\mathit{Country\ multiplier}\\ \mathit{factor}\ (\mathit{receptor})\end{matrix}$$

$$\begin{matrix}\mathit{Country\ modifier}\\ \mathit{factor}\end{matrix} = \frac{\begin{matrix}\mathit{Urban\ level\ population}\\ \mathit{weighted\ concentration}\end{matrix}}{\begin{matrix}\mathit{Total\ concentration}\\ \mathit{chang}\ \ \Delta C\ \mathit{in\ country}\end{matrix}} \times \begin{matrix}\mathit{Anthropogenic}\\ \mathit{share}\end{matrix} \quad \text{and} \quad \begin{matrix}\mathit{Total\ concentration}\\ \mathit{change}\ \Delta C\ \mathit{in\ country}\end{matrix} = \frac{\Delta C\ (\mu g/m^3)\ \mathit{due\ to\ national\ emission\ reductions}}{\mathit{Share\ of}\ \Delta C\ \mathit{attributed\ to\ national\ emission\ reductions}}$$

Note. EMEP spatially averaged country-level concentrations are transformed to population-weighted values using a country modifier factor (Table 2), which is calculated dividing the urban-level population-weighted mean concentration *(16)* by the total change in country concentration ΔC if ALL pollutant emissions from both national sources plus contributions from neighbouring countries in EMEP are reduced to zero. Finally, the modifier is multiplied by the anthropogenic contribution to ambient concentration. The total concentration change is the ratio of the attributable change due to national emission reductions and the share that these emission changes make to the total country-level concentration (see Fig. 6). The proportion contributed by national emissions is calculated using the EMEP country-to-country blame matrix (diagonal element divided by the sum of values along a row for a given receptor country or the EU28).

Table 4. Reduced population-weighted exposure in 2030 for emission reduction shown in Fig. 4

Change due to domestic emission reductions

Combined effect of national and regional reductions

Country/Region	ISO Country code	Population (thousands)	Reduced emissions (kt)					PM2.5 concentration change (µg/m3)†	
			GHG (Mt)	PM2.5	SO2	NOx	NH3	National emissions	ALL emissions
Albania	AL	2,954	1.70	0.10	0.45	0.29	0.00	0.051	0.985
Armenia	AM	2,993	6.90	0.43	0.73	4.70	0.00	0.832	3.570
Azerbaijan	AZ	10,727	25.70	6.20	20.60	28.80	0.00	3.015	3.819
Belarus	BY	8,977	38.90	3.40	11.20	10.80	0.00	0.333	1.605
Bosnia and Herzegovina	BA	3,584	-6.10	0.06	1.40	0.18	0.00	0.058	1.841
Georgia	GE	3,868	15.40	3.50	4.10	9.20	0.00	1.848	3.054
Iceland	IS	364	1.90	0.02	0.24	0.80	0.00	0.002	0.018
Israel	IL	9,998	-8.20	0.29	9.90	7.00	0.00	0.099	0.710
Kazakhstan	KZT	20,072	53.70	4.20	133.00	24.00	0.00	0.233	0.528
Kyrgyzstan	KG	7,097	17.90	0.17	1.30	1.30	0.00	0.023	0.120
Montenegro	ME	618	1.60	0.07	0.20	0.11	0.00	0.033	0.972
Norway	NO	5,945	20.80	0.58	8.30	11.40	0.00	0.298	0.728
Republic of Moldova	MD	3,839	28.40	0.14	0.23	0.23	0.00	0.026	1.655
Russian Federation	RUE	138,652	926.00	126.00	518.00	130.00	0.00	0.798	1.014
Serbia	RS	10,327	7.90	0.30	3.60	0.95	0.00	0.062	1.303
Switzerland	CH	9,223	26.70	0.25	3.50	5.20	0.00	0.314	1.322
Tajikistan	TJ	11,102	3.80	1.50	5.30	4.00	0.00	0.570	0.738
The FYR of Macedonia	MK	2,078	-2.80	1.10	19.00	3.30	0.00	1.045	2.958
Turkey	TR	87,717	-737.00	24.00	243.00	64.00	0.00	1.293	1.610
Turkmenistan	TM	6,160	-85.20	0.00	0.00	0.00	0.00	0.000	0.095
Ukraine	UA	40,892	378.00	4.10	22.00	8.80	0.00	0.104	0.994
Uzbekistan	UZ	34,397	0.00	0.00	0.00	0.00	0.00	0.000	0.522
EU-28	EU-28	509,433	2,250.00	287.00	914.00	951.00	0.00	1.634	1.710
All countries		**931,017**	**2,966**	**463**	**1,920**	**1,266**	0.00		**1.471**

† Contribution to total concentration change due to National emission reductions and change including transboundary pollution from emission reductions in neighbouring countries (ALL emissions column).

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

Note. Greenhouse gas changes are relative to base year 1990. For other pollutants, the changes are relative to the 2030 business as usual scenario.

The user can navigate to different areas in the *Summary of results* worksheet using the Jump to box located at the top right corner of the worksheet (options include: view comments, review 2020 or 2030 summary tables, and go to the figures). The user has access to all the output results and interim calculations (for example, tables of concentration changes in the four worksheets *Effect xxx reduction on PM2.5*) and may use this information to prepare additional summary tables and graphs.

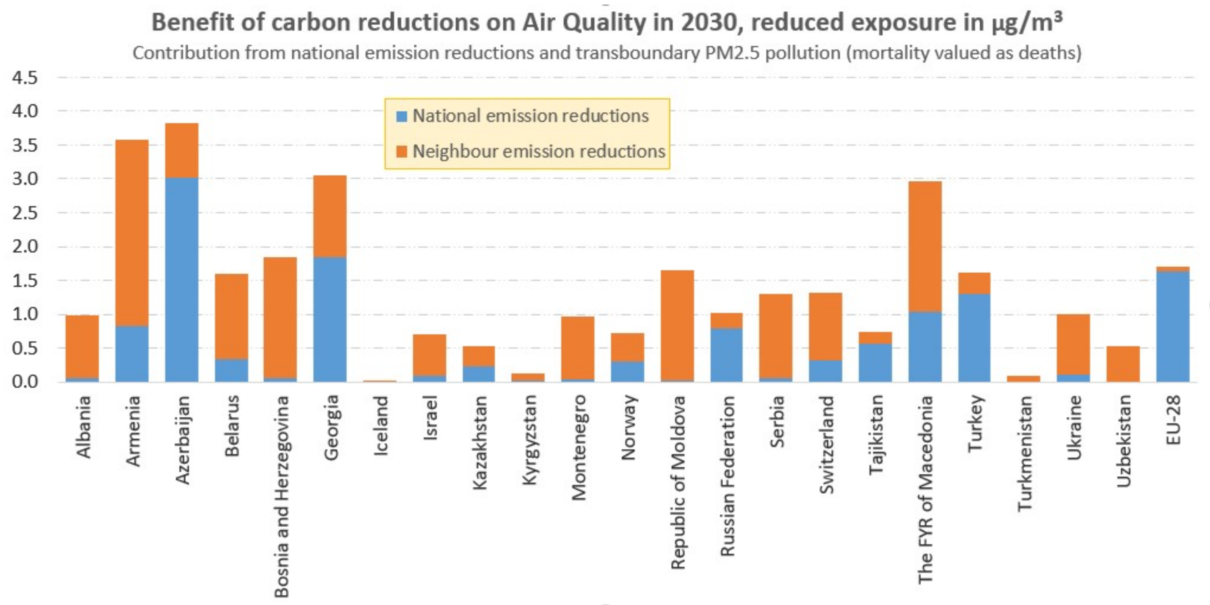
Software preloaded databases

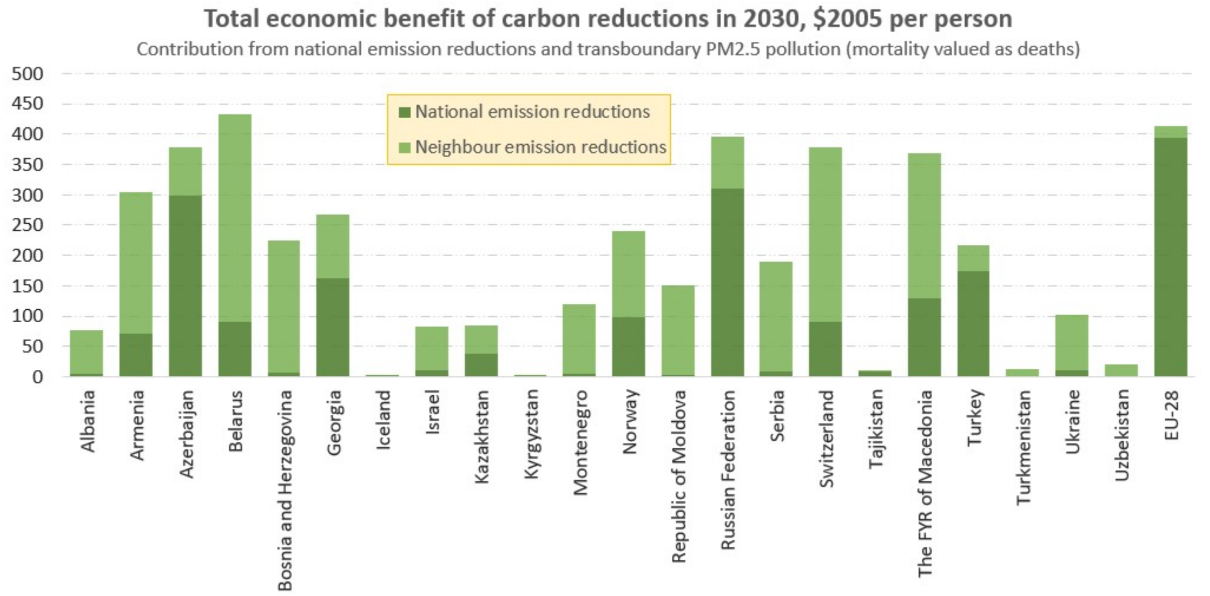
The following worksheets contain default data and background information, which can be modified or supplemented by the user:

- *Exposure costs*: contains epidemiological data, illness and mortality costs for the 53 Member States for 2010, 2020 and 2030 (Fig. 11);
- *Demographics*: contains demographic data by country for 2010 plus projections for 2020 and 2030 according to published data by *(9)*.

- manual: Health benefits of carbon reductions (this document).

Fig. 7. Air quality and economic benefits from domestic and regional emission cuts as shown in Fig. 4





The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

Note. There are significant environmental, health and economic benefits to be achieved from concerted regional efforts to limit carbon emissions, leading to win−win opportunities across all Member States.

Additional resources

The following additional resources are available.

- *Achieving health benefits from carbon reductions — Role of (intended) nationally determined contributions*. PowerPoint presentation, including a validation exercise *(10)*.
- *WHO Policy Brief: Healthy mitigation in the WHO European Region*. An application of the CaRBonH calculation tool *(11)*.
- *Background on the UNFCCC: The international response to climate change (12)*.
- *Climate Action Tracker (13)*.
- *CAIT Climate Data Explorer (14)*.

Table 5. Averted morbidity and mortality from reductions in $PM_{2.5}$ ambient concentrations in 2030

Country/Region	Children		Adults	Labor force	All ages		Mortality	
	Bronchitis	Asthma	Bronchitis	WLD	RAD	HA	Deaths	YLL
Albania	920	4,077	119	46,206	194,878	85	148	1,726
Armenia	1,730	7,664	433	141,982	750,800	521	629	6,843
Azerbaijan	8,418	37,293	1,512	558,198	2,857,027	1,939	2,151	29,305
Belarus	4,350	19,272	604	227,529	967,690	702	1,185	11,211
Bosnia and Herzegovina	1,503	6,659	301	100,513	449,007	330	481	4,668
Georgia	2,024	8,966	474	153,668	833,111	573	749	7,428
Iceland	2	11	0	93	438	0	0	3
Israel	1,656	7,336	235	106,321	484,453	200	210	2,578
Kazakhstan	2,527	11,195	345	137,573	744,813	490	551	7,066
Kyrgyzstan	233	1,031	25	10,855	60,039	38	32	491
Montenegro	92	408	24	9,507	40,688	29	39	367
Norway	1,501	6,649	175	114,060	244,053	181	199	2,134
Republic of Moldova	1,869	8,281	266	100,426	426,648	309	488	5,112
Russian Federation	43,294	191,803	5,809	1,802,951	9,858,072	6,827	11,553	114,370
Serbia	1,987	8,802	562	210,330	915,246	662	1,035	8,842
Switzerland	3,396	21,062	534	168,122	838,372	353	595	6,147
Tajikistan	2,496	11,060	225	101,744	578,006	362	259	4,476
The FYR of Macedonia	1,698	7,523	264	18,811	491,860	302	385	4,229
Turkey	55,004	243,683	5,213	862,218	10,795,510	5,495	5,012	84,276
Turkmenistan	135	597	20	7,996	40,760	27	29	466
Ukraine	12,146	53,809	1,709	244,980	3,128,289	1,981	3,669	33,793
Uzbekistan	4,204	18,625	591	242,125	1,251,492	833	807	12,710
EU-28	252,229	1,460,736	37,364	13,489,777	58,489,391	33,191	53,171	481,472
Total (thousands)	**403**	**2,137**	**57**	**18,856**	**94,441**	**55**	**83**	**830**

WLD = work lost days; RAD = restricted activity days; HA = hospital admissions; YLL = years of life lost.
The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

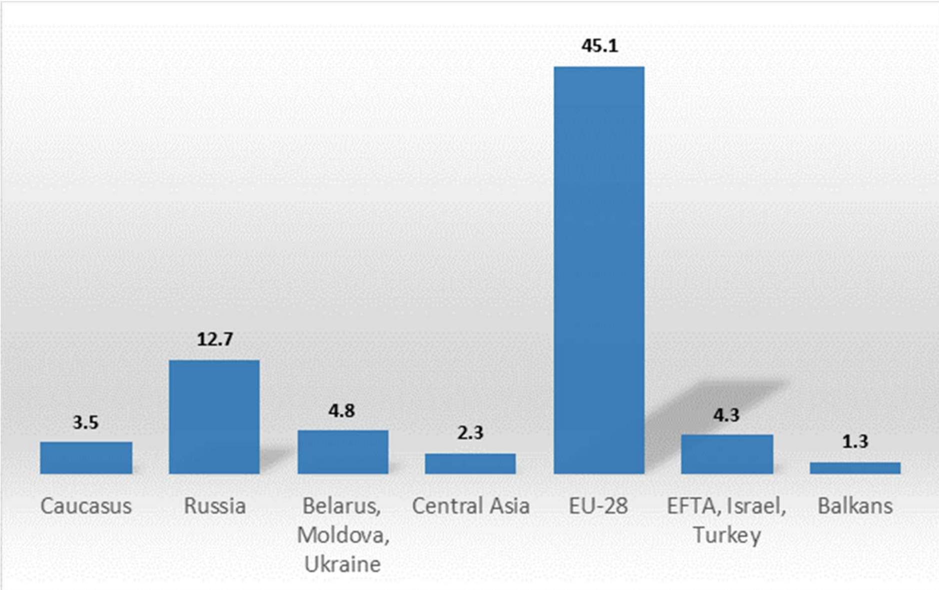
Notes.

- Implementation of NDC pledges with corresponding emission reductions shown in Fig. 4 lead to 74 000 premature deaths or 736 000 life-years gained annually. For the population alive in 2030, the reduced mortality risk is equivalent to an increase in life expectancy of around half a month (approximately 11 days gained per decrement of 1 $\mu g/m^3$ of $PM_{2.5}$).
- Equation for calculating health benefits (applied individually to each country or region and health outcome):

$$\begin{matrix}\text{Health}\\ \text{benefit}\end{matrix} = \begin{matrix}\mathrm{PM}_{2.5}\text{ concentration}\\ \text{change}\end{matrix} \times \begin{matrix}\text{Country}\\ \text{population}\end{matrix} \times \begin{matrix}\text{Concentration– response}\\ \text{function}\end{matrix}$$

- Default data on population (worksheet *Demographics*) and concentration–response functions (worksheet *Exposure costs*) are summarized in the preloaded databases.

Fig. 8. Averted annual mortality (prevented premature deaths) (thousands) from implementation of NDC pledges in the 53 Member States in 2030 for emission cuts shown in Fig. 4



Russia = Russian Federation; Moldova = Republic of Moldova.
Caucasus = Armenia, Azerbaijan, Georgia.
Central Asia = Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.
EU28 = Austria, Belgium, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.
EFTA (European Free Trade Association) = Iceland, Norway, Switzerland.
Balkans = Albania, Bosnia and Herzegovina, Montenegro, Serbia, the former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

Notes.

- The preventable mortality from reduced air pollutant emissions in 2030 is 74 000 deaths, of which 45 100 (61%) of total deaths are averted across EU member states. This figure represents around 10% of the health burden attributed to ambient air PM pollution in 2010. The health benefit in the Russian Federation equals 12 700 (or 17%) of avoidable deaths. The magnitude of these values is closely related to the exposed population size: the EU28 contribute 55% of the total exposed population, followed by the Russian Federation with 15%. In terms of years of life expectancy gained, the total benefit across Region is 736 000 life-years gained, of which 55% is attributed to EU28 countries.
- In addition to prevented mortality, improved air quality results in fewer cases of illnesses (morbidity), including 49 000 fewer hospital admissions, 1.9 million fewer incidences of asthma attacks and 350 000 prevented cases of bronchitis in children, 50 000 fewer cases of chronic bronchitis in adults and nearly 83 million restricted activity days averted plus an additional 17 million work lost days (Table 5).

Fig. 9. $PM_{2.5}$ CRF used in the CaRBonH calculation tool (2010)

Country	WHO Region	Children		Adults	Labor force	All ages (morbidity)		All ages Mortality	
		Bronchitis	Asthma	Chronic bronchitis	WLD	RAD	Hospital admissions	Deaths	YLL
Albania	Eur-B	4.51E-04	2.00E-03	3.22E-05	1.63E-02	6.60E-02	2.79E-05	3.92E-05	5.31E-04
Andorra	Eur-A	3.52E-04	2.18E-03	3.98E-05	1.51E-02	6.70E-02	3.34E-05	4.86E-05	5.33E-04
Armenia	Eur-B	1.80E-04	7.98E-04	3.37E-05	1.41E-02	6.94E-02	4.74E-05	4.91E-05	6.02E-04
Austria	Eur-A	2.84E-04	1.76E-03	4.17E-05	1.83E-02	6.42E-02	5.65E-05	5.11E-05	5.79E-04
Azerbaijan	Eur-B	2.02E-04	8.93E-04	3.10E-05	1.46E-02	6.88E-02	4.66E-05	3.81E-05	6.61E-04
Belarus	Eur-C	2.94E-04	1.30E-03	3.95E-05	1.73E-02	6.56E-02	4.87E-05	7.74E-05	8.89E-04
Belgium	Eur-A	3.24E-04	2.01E-03	4.09E-05	1.53E-02	6.69E-02	2.90E-05	5.36E-05	5.78E-04
Bosnia and Herzegovina	Eur-B	2.96E-04	1.31E-03	4.00E-05	1.70E-02	6.60E-02	4.87E-05	5.61E-05	6.97E-04
Bulgaria	Eur-B	2.67E-04	1.18E-03	4.21E-05	1.62E-02	6.68E-02	4.93E-05	8.27E-05	8.18E-04
Croatia	Eur-A	2.91E-04	1.29E-03	4.13E-05	2.05E-02	6.25E-02	3.54E-05	6.77E-05	6.93E-04
Cyprus	Eur-A	3.50E-04	1.55E-03	3.66E-05	1.69E-02	6.59E-02	1.42E-05	3.73E-05	5.39E-04
Czech Republic	Eur-A	2.73E-04	1.21E-03	4.14E-05	2.75E-02	5.56E-02	4.31E-05	5.52E-05	6.63E-04
Denmark	Eur-A	3.49E-04	2.17E-03	4.00E-05	1.54E-02	6.67E-02	3.02E-05	5.29E-05	6.04E-04
Estonia	Eur-C	2.97E-04	1.32E-03	4.02E-05	1.56E-02	6.74E-02	4.88E-05	6.50E-05	7.40E-04
Finland	Eur-A	3.19E-04	1.41E-03	4.07E-05	1.55E-02	6.73E-02	5.69E-05	5.26E-05	5.88E-04
France	Eur-A	3.52E-04	2.18E-03	3.98E-05	1.51E-02	6.70E-02	3.34E-05	4.86E-05	5.33E-04
Georgia	Eur-B	1.45E-04	6.41E-04	3.75E-05	1.40E-02	6.96E-02	4.85E-05	6.26E-05	6.71E-04
Germany	Eur-A	**2.59E-04**	1.61E-03	4.32E-05	2.56E-02	5.71E-02	5.01E-05	**5.91E-05**	**6.11E-04**
Greece	Eur-A	2.81E-04	1.74E-03	4.27E-05	1.56E-02	6.69E-02	2.97E-05	5.74E-05	6.11E-04
Hungary	Eur-C	2.86E-04	1.27E-03	4.14E-05	1.81E-02	6.49E-02	5.45E-05	7.19E-05	7.72E-04
Iceland	Eur-A	4.07E-04	1.80E-03	3.63E-05	1.59E-02	6.66E-02	2.17E-05	3.47E-05	4.80E-04
Ireland	Eur-A	4.16E-04	2.58E-03	3.68E-05	1.60E-02	6.57E-02	3.01E-05	3.47E-05	5.23E-04
Israel	Eur-A	2.37E-04	1.05E-03	3.21E-05	1.53E-02	6.80E-02	2.79E-05	2.92E-05	4.11E-04
Italy	Eur-A	2.68E-04	1.66E-03	4.37E-05	1.52E-02	6.74E-02	3.01E-05	5.28E-05	5.75E-04
Kazakhstan	Eur-C	1.96E-04	8.69E-04	3.12E-05	1.37E-02	6.97E-02	4.64E-05	4.85E-05	7.12E-04
Kyrgyzstan	Eur-B	2.56E-04	1.13E-03	2.60E-05	1.30E-02	7.01E-02	4.46E-05	3.51E-05	5.62E-04
Latvia	Eur-C	2.69E-04	1.19E-03	4.07E-05	1.61E-02	6.70E-02	5.58E-05	7.95E-05	8.05E-04
Lithuania	Eur-C	2.90E-04	1.28E-03	3.95E-05	1.45E-02	6.84E-02	7.02E-05	8.30E-05	8.17E-04
Tajikistan	Eur-B	3.07E-04	1.36E-03	2.25E-05	1.22E-02	7.08E-02	4.31E-05	3.11E-05	5.09E-04
The FYR of Macedonia	Eur-B	3.49E-04	1.54E-03	3.75E-05	3.25E-03	7.95E-02	4.77E-05	5.05E-05	6.81E-04
Turkey	Eur-B	5.28E-04	2.34E-03	3.04E-05	6.04E-03	7.59E-02	3.77E-05	3.13E-05	5.82E-04
Turkmenistan	Eur-B	2.62E-04	1.16E-03	2.66E-05	1.33E-02	6.99E-02	4.48E-05	4.24E-05	7.13E-04
Ukraine	Eur-C	2.77E-04	1.23E-03	4.03E-05	6.54E-03	7.65E-02	4.89E-05	8.35E-05	9.88E-04
United Kingdom	Eur-A	3.35E-04	2.08E-03	3.97E-05	1.07E-02	7.15E-02	2.94E-05	5.01E-05	5.66E-04
Uzbekistan	Eur-B	2.54E-04	1.13E-03	2.66E-05	1.32E-02	7.00E-02	4.48E-05	3.84E-05	6.30E-04
EU-28		3.00E-04	1.74E-03	4.13E-05	1.76E-02	6.50E-02	3.83E-05	5.43E-05	6.06E-04

259 excess incidences per million people per 1 µg/m³, annually

59 excess deaths (or 611 YOLL) per million people per 1 µg/m³, annually

WLD = work lost days; RAD = restricted activity days; YLL = years of life lost.
The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: preloaded database in CaRBonH software (worksheet *Exposure costs*).

Notes.

- CRFs have units: excess (additional) annual cases of illness (morbidity) or premature mortality (expressed as number of deaths or years of life lost) per person and for an incremental change in ambient $PM_{2.5}$ concentration of 1 µg/m³.
- CRFs are linear, meaning there is a constant change in health risk for the same increase in exposure over the entire range of plausible concentrations. In addition, it is assumed that exposure functions do not have a threshold below which there are no ill effects in the vulnerable population. Thus,

  annual burden for a specific health endpoint = ambient concentration increase × exposed population × CRF for that illness.

- CRFs are calculated using the following expressions *(17)* (it is assumed that everyone in a country is exposed at the weighted mean concentration):

$$CRF = \left(\frac{RR-1}{RR}\right)\left(\frac{1}{\Delta C}\right) \cdot \begin{matrix} Prevalence \\ rate \end{matrix} \cdot f_{pop}$$

$$CRF\ (life\ years\ lost, YLL) = Exp(8.161 - 0.04478 \cdot LE) \cdot f_{pop,30+} \cdot 10^{-5}$$

where relative risks is the relative risk of the health outcome in question *(7)*, prevalence rate is the number of cases of illness per year (or mortality rate) per person in the population at risk of illness, ΔC is the change in $PM_{2.5}$ population-weighted concentration in units of µg/m³, fpop is the share of the total population affected by the health outcome of concern (age group), fpop,30+ is the group aged 30 years and older and LE is life expectancy at birth (both sexes).

Table 6. Economic benefits from reduced $PM_{2.5}$ emissions in 2003 (US$ million, 2005 prices)

Country/Region	Children		Adults	Labor force	All ages		Mortality		TOTAL (M$2005) Mortality valued as	
	Bronchitis	Asthma	Bronchitis	WLD	RAD	HA	Deaths	YLL	Deaths	YLL
Albania	0.3	0.1	4.0	3.3	9.8	0.1	212	93	229	111
Armenia	0.6	0.2	14.1	9.5	35.7	0.8	848	349	909	410
Azerbaijan	3.5	1.1	62.0	48.7	176.5	3.2	3,769	1,942	4,064	2,237
Belarus	3.3	1.0	45.0	35.4	106.5	2.4	3,698	1,323	3,892	1,517
Bosnia and Herzegovina	0.6	0.2	11.7	7.9	25.1	0.7	762	280	808	326
Georgia	0.6	0.2	15.2	9.9	38.2	1.0	973	365	1,038	430
Iceland	0.0	0.0	0.0	0.0	0.1	0.0	1	0	1	0
Israel	1.4	0.4	19.8	18.2	58.6	0.8	719	335	819	434
Kazakhstan	1.7	0.5	23.3	19.5	74.7	1.4	1,566	760	1,687	881
Kyrgyzstan	0.0	0.0	0.3	0.3	1.2	0.0	18	10	20	12
Montenegro	0.0	0.0	1.0	0.8	2.6	0.0	69	25	73	29
Norway	2.4	0.7	28.6	37.3	56.5	1.6	1,303	530	1,430	657
Republic of Moldova	0.5	0.1	7.4	5.6	16.8	0.5	544	216	575	246
Russian Federation	45.9	13.9	594.5	405.6	1,569.6	23.1	52,186	19,536	54,838	22,189
Serbia	0.8	0.3	23.2	18.8	58.0	1.0	1,862	601	1,964	704
Switzerland	4.5	1.8	71.7	45.1	159.0	2.6	3,204	1,251	3,488	1,535
Tajikistan	0.2	0.1	2.2	2.1	8.3	0.2	105	69	118	82
The FYR of Macedonia	0.8	0.2	11.8	1.7	32.3	0.6	717	298	765	346
Turkey	44.6	13.4	413.3	146.9	1,301.4	16.7	17,141	10,899	19,077	12,835
Turkmenistan	0.1	0.0	1.1	0.9	3.3	0.1	67	41	72	46
Ukraine	3.2	0.9	44.8	13.2	119.0	2.5	3,960	1,380	4,144	1,563
Uzbekistan	0.8	0.2	10.8	9.2	33.5	0.7	612	365	668	420
EU-28	246.4	95.1	3,703.5	2,662.9	8,201.8	175.7	195,093	71,441	210,179	86,527
Total (million $)	**362.2**	**130.4**	**5,109**	**3,503**	**12,088**	**235.5**	**289,429**	**112,108**	**310,858**	**133,536**

WLD = work lost days; RAD = restricted activity days; HA = hospital admissions; YLL = years of life lost.
The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: CaRBonH software.

Notes.

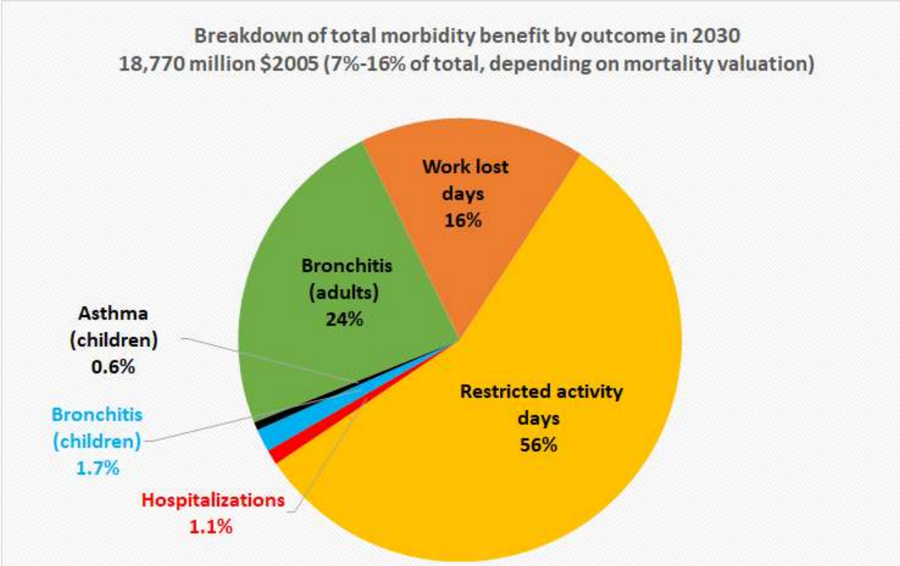
- The economic cost of prevented illnesses and mortality in 2030 is US$ 277 billion (2005 prices) if valuing postponed premature deaths (or US$ 97 billion if valuing life-years gained). Put another way, these results represent between 0.5% and 1.2% of the annual GDP of the 53 Member States. The EU28 contribution is 64% (or 75% if valuing mortality as life-years gained). The prevented health morbidity alone contributes about US$ 19 billion (Fig. 4).
- Equations for calculating economic benefits (applied individually to each country or region and health outcome):

$$\begin{matrix} economic \\ benefit \end{matrix} = \begin{matrix} population \\ exposure \end{matrix} \times \begin{matrix} exposure \\ cost \end{matrix} \quad \text{and} \quad \begin{matrix} exposure \\ cost \end{matrix} = CRF \times \begin{matrix} cost\ per\ case\ of\ illness \\ (or\ death, years\ of\ life\ lost) \end{matrix}$$

  Default data on exposure costs are summarized in the worksheet *Exposure costs*.

- Morbidity costs are market expenditures (included in the transaction costs of doing business); they have a direct consequence on a country's GDP and, at the level of the citizen, impact the quality of life and indirectly affect personal income and savings. Mortality benefits are not market costs; instead the economic benefits represent a gain in social well-being, or welfare, from reduced pain and suffering associated with air pollution as a risk factor.

Fig. 10. Morbidity benefits from implementation of NDC pledges for emission reductions shown in Fig. 4

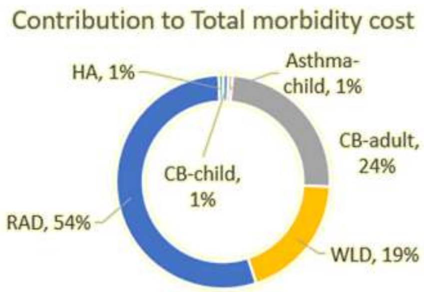


Source: CaRBonH software.

Fig. 11. Costs of illness and mortality for selected countries (US$ per case at 2005 prices, undiscounted)

Unit costs for Year 2010

Country	Children Bronchitis	Children Asthma	Adults Chronic bronchitis	Labor force WLD	All ages (morbidity) RAD	All ages (morbidity) Hospital admissions	All ages Death VSL	All ages Death VOLY
Albania	205	14	19,868	43	31	698	868,753	32,852
Andorra	894	58	92,479	180	127	5,491	3,612,824	136,619
Armenia	110	7	10,640	23	16	377	464,700	17,573
Austria	877	57	91,456	175	124	5,734	3,514,318	132,894
Azerbaijan	241	17	23,293	51	36	780	1,025,922	38,795
Belarus	322	22	31,263	68	48	1,118	1,363,403	51,557
Belgium	827	54	85,079	167	118	4,884	3,355,896	126,903
Bosnia and Herzegovina	198	13	20,068	41	29	1,037	813,665	30,769
Bulgaria	307	21	30,519	64	45	1,343	1,282,574	48,501
Croatia	438	29	43,486	91	64	1,911	1,827,923	69,123
Cyprus	610	41	59,486	128	91	2,213	2,577,686	97,475
Czech Republic	583	39	58,090	121	86	2,617	2,429,471	91,870
Denmark	870	57	89,413	176	125	5,097	3,533,706	133,627
Estonia	478	33	46,646	101	71	1,726	2,022,992	76,499
Finland	781	52	79,138	160	113	4,081	3,210,378	121,401
France	787	51	81,404	158	112	4,833	3,180,175	120,258
Georgia	112	7	11,540	23	16	659	455,837	17,237
Germany	829	54	86,340	166	117	5,339	3,332,009	126,000
Greece	637	42	64,531	130	92	3,328	2,617,761	98,991



Abbreviations

HA – Hospital admissions
RAD – Restricted activity days
WDL – Work loss days (absenteeism)
CB – Chronic bronchitis
VSL – Value of a statistical life
VOLY – Value of a life year

Year 2030

Country	Children Bronchitis	Children Asthma	Adults Chronic bronchitis	Labor force WLD	All ages (morbidity) RAD	All ages (morbidity) Hospital admissions	All ages Death VSL	All ages Death VOLY
Albania	340	23	33,479	71	50	1,381	1,424,703	53,875
Andorra	1,166	76	120,552	235	166	7,157	4,709,550	178,092
Armenia	325	22	32,515	67	48	1,526	1,347,988	50,974
Austria	1,122	73	116,561	225	159	7,119	4,515,455	170,752
Azerbaijan	417	28	40,981	87	62	1,647	1,752,250	66,261
Belarus	750	50	74,634	155	110	3,360	3,121,750	118,049
Belgium	1,081	71	110,815	219	155	6,213	4,399,651	166,373
Bosnia and Herzegovina	385	25	38,957	79	56	1,991	1,583,886	59,895
Bulgaria	519	35	51,889	107	76	2,429	2,152,404	81,393
Croatia	598	40	59,863	124	88	2,800	2,483,652	93,919
Cyprus	591	40	57,605	124	88	2,126	2,499,478	94,518
Czech Republic	834	55	84,089	171	121	4,190	3,439,541	130,066
Denmark	1,138	75	115,757	232	164	6,143	4,662,679	176,319
Estonia	954	64	94,469	199	141	4,065	3,987,594	150,791
Finland	1,053	70	106,615	215	152	5,493	4,326,183	163,595
France	1,021	67	104,840	206	146	5,966	4,145,563	156,765
Georgia	317	21	32,147	65	46	1,682	1,299,473	49,140
Germany	1,061	69	109,693	213	151	6,523	4,283,355	161,975
Greece	867	57	87,958	177	126	4,573	3,561,224	134,668

Source: preloaded database in CaRBonH software (worksheet *Exposure costs*).

Notes.

- *Health outcomes*. Children: bronchitis (6–12 years); asthma symptom days (5–19 years). Adults: new cases of chronic bronchitis (27+ years); work lost days due to absenteeism (labour force aged 18–64 years). All ages: restricted activity days; hospital admissions; mortality (valuation based on the value of statistical life applied to number of deaths, or the value of a life-year applied to loss of life expectancy).

- *Cost adjustment from country A to country B (benefit transfer method)*. Ideally, national or regional studies should be used to value local economic losses due to air pollution. In the absence of such data, however, the equation below may be used to transfer unit health costs from another site (study) to the current location *(18)*.The adjustment takes into account differences in income levels between the two places, with all other socioeconomic conditions assumed to be similar. Here, Y is the GDP per capita (at purchasing power parity prices), and β is an income elasticity factor, whose values are 0.8, 0.9 and 1.0, respectively, for high, upper middle and lower middle-income countries *(8)*.

$$Cost_{Country\ B} = Cost_{Country\ A} \cdot \left(\frac{Y_{Country\ B}}{Y_{Country\ A}}\right)^{\beta}$$

- *Cost adjustment over time (income growth effect)*. Future costs are calculated using the following expression, where tref and t represent, respectively, the reference and future times. Future GDP/capita growth is based on the real income growth rate (constant currency, no inflation). Often, the elasticity of marginal utility of consumption δ is assumed to be equal to the income elasticity β.

$$Cost(t) = Cost(t_{ref}) \cdot \left(\frac{Y_t}{Y_{t_{ref}}}\right)^{\delta}$$

References

1. United Nations. United Nations Framework Convention on Climate Change; 1992 (https://unfccc.int/resource/docs/convkp/conveng.pdf [Accessed 30 November 2017].
2. Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE et al., editors. Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York (NY): Cambridge University Press; 2014 (https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-FrontMatterA_FINAL.pdf, accessed 21 June 2018).
3. The Paris Agreement [website]. Bonn: United Nations Framework Convention on Climate Change; 2014 (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed 21 June 2018).
4. Nationally determined contributions (NDCs) [website]. Bonn: United Nations Framework Convention on Climate Change; 2014 (https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs, accessed 21 June 2018).
5. Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components – EMEP Status Report 1/2015. Oslo: European Modelling and Evaluation Programme (EMEP), Norwegian Meteorological Institute; 2015 (http://emep.int/publ/reports/2015/EMEP_Status_Report_1_2015.pdf, accessed 21 June 2018).
6. Rabl A, Spadaro JV, Holland M. How much is clean air worth? Calculating the benefits of pollution control. Cambridge: Cambridge University Press; 2014 (https://www.exlibris.ch/fr/livres/livres-anglais/ari-rabl/how-much-is-clean-air-worth/id/9781107043138, accessed 21 June 2018).
7. Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. Copenhagen: WHO Regional Office for Europe; 2013 (http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide, accessed 21 June 2018).
8. Organisation for Economic Co-operation and Development. The economic consequences of outdoor air pollution. Paris: OECD Publishing; 2016 (https://read.oecd-ilibrary.org/ environment/the-economic-consequences-of-outdoor-air-pollution_9789264257474-en#page1, accessed 21 June 2018).
9. World population prospects: the 2015 revision. New York (NY): United Nations Department of Social and Economic Affairs; 2015 (http://www.un.org/en/development/desa/publications/world-population-prospects-2015-revision.html, accessed 21 June 2018).
10. Spadaro J [online presentation]. Achieving health benefits from carbon reductions − Role of (intended) nationally determined contributions. 2017 (https://www.researchgate.net/publication/321421982?channel=doi&linkId=5a213898aca27229a06eb6b9&showFulltext=true], accessed 21 June 2018].
11. Policy brief – Healthy mitigation in the WHO European Region. Copenhagen: WHO Regional Office for Europe; undated (http://www.euro.who.int/__data/assets/pdf_file/0005/341744/POLICY-BRIEF-9-June-2017-edited-v2-added-paragraph_APPROVED-PCR.pdf, accessed 21 June 2018).
12. The latest on Climate Action [website]. Bonn: United Nations Framework Convention on Climate Change;2018 (https://unfccc.int/climate-action , accessed 16 November 2018).
13. Climate Action Tracker [website]. Place: CAT Consortium; 2017 (http://climateactiontracker.org/, accessed 21 June 2018).
14. CAIT Climate Data Explorer [website]. Washington (DC): World Resources Institute; 2017 (http://cait.wri.org/, accessed 21 June 2018).
15. GAINS-Europe [website]. Laxenburg: International Institute for Applied Systems Analysis; 2017 (http://www.iiasa.ac.at/web/home/research/researchPrograms/air/Europe.html, accessed 21 June 2018).
16. Ambient air pollution: A global assessment of exposure and burden of disease. Geneva: World Health Organization; 2016 (http://www.who.int/iris/handle/10665/250141, accessed 21 June 2018).

17. Holland M. Implementation of the HRAPIE recommendations for European air pollution CBA work. Luxembourg: European Medical Research Council; 2014 (http://ec.europa.eu/environment/air/pdf/CBA%20HRAPIE%20implement.pdf, accessed 21 June 2018).
18. Valuing mortality risk reductions in regulatory analysis of environmental, health and transport policies: policy implications*.* Paris: Organization for Economic Co-operation and Development; 2011 (http://www.oecd.org/env/tools-evaluation/48279549.pdf, accessed 21 June 2018).

Annex 1. Historical emissions of aggregate greenhouse gases in CO_2 equivalent metric tons (without land use, land use change and forestry)

Country/Region	1990	2000	2010	2015
Albania	4.34	5.78	8.13 (2009)	
Andorra		No data		
Armenia	25.00	5.53	7.20	
Azerbaijan	73.40	40.60	48.00	51.80 (2012)
Belarus	137.00	81.30	93.90	89.60
Bosnia and Herzegovina	34.00	15.20	28.00	31.10 (2011)
Georgia	38.70	10.60	12.90	16.60 (2013)
Iceland	3.54	3.87	4.65	4.54
Israel		67.20	77.30	78.60 (2013)
Kazakhstan	389.00	193.00	309.00	301.00
Kyrgyzstan	28.40	9.28	12.80	
Monaco	0.10	0.11	0.09	0.08
Montenegro	5.71	5.61	4.02	3.86 (2011)
Norway	51.70	54.60	55.20	53.90
Republic of Moldova	43.40			
Russian Federation	3768.00	2273.00	2601.00	2651.00
San Marino			0.27	
Serbia	80.80	66.30 (1998)		
Switzerland	53.40	52.40	54.40	48.00
Tajikistan	24.20	6.75	8.18	
The FYR of Macedonia	13.30	12.10	11.50 (2009)	
Turkey	214.00	296.00	407.00	475.00
Turkmenistan		50.30	66.40	
Ukraine	962.00	427.00	413.00	323.00
Uzbekistan	180.00	198.00	199.00	205.00 (2012)
EU	5643.00	5152.00	4775.00	4308.00

The FYR of Macedonia = The former Yugoslav Republic of Macedonia.
Source: Greenhouse gas inventory data – detailed data by party [online database]. Bonn: United Nations Framework Convention on Climate Change; 2018 (http://di.unfccc.int/detailed_data_by_party, accessed 23 June 2018).

The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

Member States

Albania
Andorra
Armenia
Austria
Azerbaijan
Belarus
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czechia
Denmark
Estonia
Finland
France
Georgia
Germany
Greece
Hungary
Iceland
Ireland
Israel
Italy
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Luxembourg
Malta
Monaco
Montenegro
Netherlands
Norway
Poland
Portugal
Republic of Moldova
Romania
Russian Federation
San Marino
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Tajikistan
The former Yugoslav
  Republic of Macedonia
Turkey
Turkmenistan
Ukraine
United Kingdom
Uzbekistan

World Health Organization
Regional Office for Europe

UN City, Marmorvej 51, DK-2100 Copenhagen Ø, Denmark
Tel: +45 45 33 70 00   Fax: +45 45 33 70 01
Email: eurocontact@who.int
Website: www.euro.who.int